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Methyl bromide alternatives

Vol. 4, No. 2

April 1998



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Using Natural Plant Volatiles: A Joint US/Israeli/South African Venture

The challenge of finding viable alternatives to methyl bromide has brought about a unique consortium of scientists from the United States, Israel, and South Africa. These scientists are pooling their knowledge and energies to develop natural plant volatiles that could serve as alternatives to methyl bromide for fumigating fruit, soil, and grain storage facilities.

"For years methyl bromide has been vital in fumigating soil for growing row crops and nursery seedlings," says Charles L. Wilson, a plant pathologist with USDA's Agricultural Research Service at Kearneysville, WV. "It is also used extensively as an export quarantine treatment for fruit and vegetables and in granaries to protect grain from pests. Natural plant compounds have been used effectively in all these areas and could be potential replacements for methyl bromide, since it will no longer be available to growers after January 1, 2001."

Wilson and Eli Shaaya of the Volcani Center in Bet Dagan, Israel, have identified natural plant compounds that could serve as alternatives to methyl bromide as a soil fumigant. They've also developed a way to determine the effect these compounds have on soilborne pathogens, fruit, and grain storage facilities. South African plant pathologist Johan Combrink and colleagues are studying a number of South African plants for compounds that could possibly replace methyl bromide. Combrink is with the INFRUTEC Center for Fruit Technology of the Fruit, Vine, and Wine Research Institute, Agricultural Research Council, in Stellenbosch, South Africa.

United States

As coordinator of the consortium, Wilson keeps in close communication with his counterparts in Israel and South Africa.

"We have collaborative research going on in each of the three countries," Wilson says. "One of the first problems we tackled was the difficulty in evaluating the effectiveness of fumigants applied to planting beds or greenhouse

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

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containers to control pathogens, insects, and weed seeds. This type of research requires large volumes of soil to be fumigated and elaborate evaluation procedures devised to test a fumigant's effectiveness. Along with Deborah Fravel, a plant pathologist with ARS at Beltsville, Maryland, we built an apparatus that quickly and easily evaluates the effectiveness of a fumigant to control soil pathogens." The research is conducted cooperatively at the ARS Appalachian Fruit Research Station in Kearneysville, West Virginia, and at the ARS Biocontrol of Plant Diseases Laboratory in Beltsville, Maryland.

The soil fumigation apparatus is simple to use. A nitrogen tank is hooked to a stainless steel, gas-tight compartment that holds a plastic container filled with charcoal which absorbs the fumigant. This compartment is connected by a hose to a stainless manifold to which six, cigar-shaped soil containers are attached, with a gas-flow regulator at the top of each container. Each container has an outlet nipple at the bottom with a flow meter attached.

"This equipment allows the soil to retain uniform amounts of the fumigant for a definite period. Once the soil is fumigated, the containers are opened and the soil can be tested for fungal activity," Wilson explains. "The apparatus will speed up the process of testing natural compounds as soil fumigants."

Wilson has already successfully used this system to evaluate

several naturally occurring plant compounds.

"We found that benzaldehyde plus nitrogen controlled four major soil pathogens: *Fusarium oxysporum*, *Rhizoctonia solani*, *Phythium aphanidermatum*, and *Sclerotinia minor*," Wilson reports. "Benzaldehyde would be a desirable alternative to methyl bromide since it is inexpensive, easily biodegradable, and breaks down into products that aren't harmful to humans, animals, or the environment."

Wilson found that although soil fumigated with benzaldehyde initially had significantly lower soil pH values, within 2 weeks the pH returned to previous nonfumigated levels. Therefore, the changes in soil pH are readily reversed and should not interfere with crop production.

"In evaluating natural plant compounds as alternatives to methyl bromide, we need more research on the biocidal activity of these compounds against a wide range of pathogens and insects, as well as weeds," Wilson says. "We also need to look not only at the efficacy of natural fumigants in different soil types and different applications, but at delivery systems as well."

The Israeli Connection

At the Department of Stored Products at The Volcani Center in Israel, Eli Shaaya and colleagues have found several essential oils extracted from herb and spice plants that are effective as fumigants. They have successfully used these natural fumigants to control

pests in grain and dry, stored food products and quarantine insects in cut flowers for export. (See *Phyto-Oils Control Insects in Stored Products and Cut Flowers*, *Methyl Bromide Alternatives*, January 1998, pp. 6-7.)

South Africa's Contribution

Wilson has been working with the Fort Hare University in the eastern Cape of South Africa to find natural compounds that might replace methyl bromide.

"We've got two small South African companies, Ulimocor and the Ciskei Agricultural Corporation, interested in this project," Wilson says. "And there is a pilot plant operating at Fort Hare University to extract essential oils from indigenous South African plants."

These oils are now being marketed as flavor and fragrance compounds, and Wilson thinks they provide a potentially rich source of new compounds that may be candidates for fumigating soil, agricultural commodities, and physical structures.

Wilson has also been collaborating with Johan Combrink of INFRUITEC at Stellenbosch, South Africa, on research to find natural plant compounds that fight *Botrytis cinerea*, *Penicillium expansum*, *Mucor piriformis*, and *Rhizopus nigricans*. These pathogens attack pome fruit and are now controlled with synthetic pesticides.

The South African group, consisting of researchers from

INFRUITEC and the Plant Protection Research Institute (part of the South African Agricultural Research Council), will also address the following problems:

- Controlling weevils, the dried fruit moth and mites on dried fruit.
- Fighting the root-knot nematode (*Meloidogyne javanica*), a worldwide pest and one of the most significant nematode pests on a wide range of crops, including stone fruits and vegetables. Glasshouse colonies are available in South Africa.
- Containing the ring nematode (*Criconebella xenoplax*), a serious pest of stone fruit and peach orchards not only in South Africa, but in Georgia and South Carolina as well.
- Fumigating to control soilborne pathogens on specific crops such as Fusarium wilt on melons, root rot on strawberries, *Phytophthora* root rot on citrus, replant syndrome on apples, clubroot on cabbage, and damping-off on vegetable crops.

“We expect that this collaborative research effort will produce patentable products that can be commercialized,” Wilson reports. “The Maktishim Chemical Company in Israel is interested in our work, and we’ve been talking with a couple of U.S. companies about our results.”

Controlling Methyl Bromide Emissions with Impermeable Films

Methyl bromide is critical to agriculture worldwide as a soil fumigant, a postharvest storage treatment, and a quarantine treatment to control many pests on various crops. The primary use is to fumigate the soil to destroy soilborne pests, but unfortunately, some of the chemical escapes from the soil into the atmosphere. Methyl bromide has been declared an ozone depletor and, under provisions of the U.S. Clean Air Act, will be banned from production and importation in the United States on January 1, 2001.

But, scientists with USDA’s Agricultural Research Service and the University of California have developed new technology that can greatly reduce methyl bromide emissions from soil fumigation.

“In a recently completed field experiment, we used a virtually impermeable film (VIF), which we left on the field for 10 to 15 days, and reduced methyl bromide emissions up to 96 percent,” reports Scott R. Yates. Yates and ARS colleagues Dong Wang, Jay Gan, and Fred Ernst, with the U.S. Salinity Laboratory in Riverside, California, worked with William A. Jury, University of California-Riverside, on the project.

“The new plastic seems to have physical and mechanical properties similar to conventional plastic, so

it can be used readily in the field,” Yates says. “Growers would need to make very few changes in their fumigation practices.”

In a recently released report, the Environmental Protection Agency estimates that the new films would cost about 47 percent more than conventional films. That, Yates says, is based on the fact that the films are not produced in the United States and are not yet produced in mass quantity. “Mass production would probably bring the cost of the VIF films more in line with what growers are now paying for conventional films.”

Growers now pay between \$275 and \$314 per acre for conventional, or high-density, polyethylene film (HDPE). VIF films are estimated to initially cost about \$580 per acre.

According to Yates, tests in the laboratory showed that the new plastic film—Hytibar™—is at least 75 times more effective at keeping methyl bromide gas in the soil than conventional plastic films. “When we repeated these tests in fields, Hytibar™ was about 200 times more effective than the plastic now being used.”

Yates says the wide range is due to difficulty in measuring the extremely low permeability of the new film. “We’re working on ways to more accurately measure film permeability.”

“Soil is conventionally fumigated under HDPE film. Using the new VIF film for 10 to 15 days could cut the global methyl bromide emissions from soil fumigation

from 33 percent to less than 1 percent of the total global sources,” Yates says.

Emission Rates: Old Films

Growers typically inject methyl bromide in the soil at the rate of 250 lb/acre, about a foot deep, and cover the field with HDPE plastic for 2 to 5 days. Yates and colleagues conducted an experiment testing three scenarios: HDPE film with an application rate of 250 lb/acre (standard rate of application), VIF at 188 lb/acre (75 percent of the standard rate) and VIF at 125 lb/acre (50 percent of standard).

With HDPE, total emission losses were between 56 and 68 percent of the original amount applied. “These large losses are primarily due to the ineffectiveness of the plastic film in trapping gases,” Yates explains. “Growers use this type of film because it’s relatively inexpensive and easy to use.”

The variability in the rate of loss can be due to differences in soil and environmental conditions indigenous to the location of the experiment and in the ways of measuring the emissions rate. Ambient temperature during fumigation and local variations in soil degradation are principal factors for the wide range in reported total loss. According to Yates, permeability of HDPE films is strongly temperature dependent and increases from 1.5 to 2 times for each 18 °F temperature increase. How well the soil breaks down methyl bromide depends on the soil type and organic matter content.

Emission Rates: New Films

Total emission losses from fields covered with VIF for 5 days were reduced to 36–39 percent with most of the loss occurring immediately after the plastic was removed from the soil surface. “When we left the new plastic on the fields for 10 to 15 days, total methyl bromide losses were less than 4 percent,” Yates reports. The accuracy of the 4 percent emission rate was confirmed by measuring soil degradation of methyl bromide 43 days after application; the soil degraded 96 percent of the methyl bromide applied (± 2 percent).

The new plastic, manufactured by Klerk’s Plastic in Belgium, is made by putting a barrier polymer (ethylene vinyl alcohol) between two layers of polyethylene. This makes the new film less permeable and therefore better able to keep the chemical from escaping into the air. Ultimate emission rates are greatly affected by the soil’s ability to degrade methyl bromide. Once methyl bromide breaks down, it releases a bromide ion (Br) into the soil and is no longer harmful to the atmosphere. Yates says that traditionally used plastics are too permeable to keep the chemical in the soil long enough for it to fully degrade.

“We noted that for the plots covered with VIF, the same fractional percent of total volatilization occurs regardless of the initial application rate,” Yates says. “From this we can estimate how much methyl bromide would be lost if VIFs were used instead of HDPE.”

Yates and colleagues also showed that methyl bromide application rates could be reduced if VIFs were used. Since very little of the chemical escapes, the standard application can be decreased while maintaining the same level of pest control. And, using reduced application rates would further reduce methyl bromide emissions into the atmosphere from soil fumigation.

According to Yates, there are serious questions about whether the methyl bromide ban will have any significant effect on stratospheric ozone levels. It has been suggested that the oceans act as a buffer by contributing methyl bromide to the atmosphere which will offset any reduction. And, a recently completed ARS study shows that plants living in soils containing the bromide ion may produce significant quantities of methyl bromide. This could mean a loss to the agricultural community and society, since the ban will wipe out an effective soil sterilant but do little to stop ozone depletion.

“We plan further research on VIF films at different locations and under different soil and environmental conditions,” Yates says.

Tri-Cal: Industry Research on Impermeable Films

Tri-Cal, a company in Hollister, California, has been experimenting with less permeable films for chemical fumigants for about a decade. For nearly 40 years,

California farmers have depended on Tri-Cal to apply fumigants like methyl bromide, chloropicrin, and telone to soil where trees, vines, and tomato, strawberry and pepper crops are grown.

Dean Storkan, Tri-Cal's president, says that historically their research efforts have been aimed at decreasing the dosage of methyl bromide. "When we first began using these films about 10 years ago, we reduced the amount of methyl bromide needed for some uses by about 10 to 25 percent. As commercial films became even better, we got lower emission rates," he reports.

But, according to Storkan, part of the reduced emission rates came as a result of buffer zones instituted by the state of California's Department of Pesticide Regulation (DPR). (See "California Monitors Methyl Bromide Applications for 6 months," *Methyl Bromide Alternatives*, Oct. 1997, pp. 5-6.) In 1993, DPR and California county agricultural commissioners set up parameters for buffer zones to better protect workers and others who may be exposed if methyl bromide escapes fumigation sites.

For its trials with the new impermeable films, Tri-Cal has the capability to measure methyl bromide concentrations under the tarp, but expects that California's DPR will monitor the applications on the periphery to ensure emissions are in line with mandated buffer zones.

"We, like Scott Yates of ARS, are now working with virtually impermeable films (VIF)," Storkan

says. "These films are not yet commercially available, but we're testing their permeability and strength under true commercial crop production conditions. In fact, we have cooperative growers who are now trying these films. We hope the films will be commercially available in the fall of 1998."

In addition to permeability and strength, he says that Tri-Cal is also studying the glue used to hold VIFs together. "Growers now glue tarps together to cover fields. We're looking at how this glue works in sealing methyl bromide gas in the soil instead of allowing it to escape into the atmosphere. Durability of the plastic is also vitally important. Impermeability is what we're after, but if the sheet of plastic becomes full of holes, we've defeated our purpose in reducing emissions."

Storkan says that Tri-Cal is also looking at other chemicals as possible alternatives to methyl bromide. "We're investigating the use of chloropicrin, telone, basamid, metam sodium, and methyl bromide. And, we're experimenting with combinations of these chemicals," he reports. "We feel that through our own research and our cooperative research with scientists from federal and state governments and universities, we may find a viable alternative for methyl bromide for some uses on some crops. But, some of the potential alternatives will create new environmental issues."

Tri-Cal is also working cooperatively with Plastopil Hazorea, a

company in Israel, on a project to produce a new soil fumigant package that will improve environmental quality as well as help U.S. and Israeli farmers.

ARS Soil Solarization: Fort Pierce, Florida

Florida fresh market tomato and pepper growers account for about 33 percent of the methyl bromide used for soil fumigation in the United States. Without methyl bromide, production could potentially decline, unless suitable alternatives to manage soilborne pests are found.

"For more than 30 years, Florida farmers have used production systems that rely on the use of a broad spectrum fumigant to disinfest the soil prior to planting," says Dan O. Chellemi, ARS plant pathologist. "Implementing biologically based alternatives has been especially challenging to production systems that use soil fumigants."

Last year, the ARS Horticultural Research Laboratory in Orlando hired Chellemi from the University of Florida to look into this problem at Fort Pierce, Florida. The ARS Orlando lab is expected to relocate to Fort Pierce in 1999, if lab construction is completed on schedule. "Our mission is to come up with biologically based alternatives to methyl bromide," Chellemi says. "To do this, we must either devise an integrated pest management (IPM) strategy to control soilborne pests of vegetable crops or we must develop alternative

production systems that minimize the impact of soilborne pests.”

Since methyl bromide will no longer be available to growers after January 1, 2001, Chellemi says that in the short term, methyl bromide could be replaced with another broad spectrum soil fumigant or fumigant/herbicide combination. An intermediate solution could be an IPM approach that combines multiple tactics such as chemicals, soil solarization, and cultural practices. And, he says, production systems designed to minimize outbreaks of potential pests could be a long-term alternative to soil fumigation.

Over the past 3 years, Chellemi and collaborators from industry and the University of Florida evaluated soil solarization—alone or combined with 1,3-dichloropropene (1,3-D), 1,3-D and chloropicrin, or municipal solid waste compost—on tomato, pepper, cucumber, and pumpkin production. The research plots were located in several southern and northern Florida counties, as well as in southern Georgia.

Soil solarization is a hydrothermal process in which clear plastic is stretched over moistened soil to trap solar energy and heat the soil. Over a 6- to 8-week period, this procedure can control many of the soilborne pests that attack Florida's fresh market vegetables.

“Although yields in solarized plots were similar to those in methyl bromide-fumigated plots, pest control varied among the locations,” Chellemi reports.

Tomatoes

Field plots were established on seven farms located from the southeastern coast of Florida to southern Georgia, with size ranging from a little more than an acre to 2.5 acres. Plots were treated with soil solarization, solarization combined with reduced rates of 1,3-D, standard applications of 1,3-D plus chloropicrin, or methyl bromide.

“On three farms, methyl bromide outyielded soil solarization. Yield with solarization was greater on one farm and yield with 1,3-D plus chloropicrin was greater on one farm,” Chellemi reports. “Solarization suppressed weeds about the same as methyl bromide in all locations except when purslane and Texas panicum were present.”

And, he says, solarization controlled southern blight better than methyl bromide but was not as good at controlling root-knot nematodes. However, combining solarization with reduced applications of 1,3-D or 1,3-D plus chloropicrin achieved nematode control comparable with that of methyl bromide.

“All tomato growers who participated in this study indicated that they could use soil solarization in their existing production systems,” Chellemi reports.

Peppers

The experimental plot for peppers consisted of 10 adjacent beds of Myakka sandy soil covered with 28 tons per acre of a mixture of moist

biosolids and yard waste, 1.1 tons per acre of dried municipal solid waste compost and 73–39–38 pounds of N–P–K, respectively, per acre. Chellemi and colleagues covered the beds with clear, 1.2-mil-thick, low-density plastic containing ultraviolet light inhibitors. They pulled test plants to measure the severity of root galling by root-knot nematodes and collected soil samples to check for nematodes. In a nearby control plot, they applied mineral fertilizer to soil fumigated with methyl bromide and chloropicrin.

Cucumbers

After the last peppers were picked, Chellemi and colleagues mowed the plants, side dressed the rows with 250 pounds per acre of fertilizer, punched new holes in the plastic, and planted cucumbers.

In another location, cucumbers were grown as the main crop and three treatments were used: soil solarization, methyl bromide plus chloropicrin fumigation, and an untreated control. Again, they evaluated plant roots for galling and tested soil samples for nematodes. Using drip irrigation, they injected fertilizer weekly.

Pumpkins

On the pumpkin raised-bed test plots, the researchers used soil solarization alone, solarization plus 1,3-dichloropropene (8 gal per treated acre) and an untreated control. As with peppers and cucumbers, root gall ratings were taken for each treatment and soil samples were taken for nematodes.

Results

"In general, we got greater yields from methyl bromide-treated plots than from the solarized plots," Chellemi reports. "But pest levels were low in both treatments."

Actual data showed that marketable yield of peppers was 15.3 tons per acre from solarized plots, compared to 16.4 tons per acre for plots fumigated with methyl bromide. But suppression of nutsedge and control of nematodes were similar under both treatments, Chellemi says.

A second crop of cucumbers showed reduced marketable yield, increased severity of root galling, and more nematodes in solarized beds. In Washington County, Florida, severe root galling and lots of root-knot nematodes occurred in untreated and solarized beds, but not in beds treated with soil solarization plus 1,3-D.

In Suwannee County, soil-solarized and methyl bromide-fumigated plots suppressed yellow and purple nutsedge at about the same rate. Methyl bromide test plots produced the greatest marketable yield with less root galling and fewer root-knot nematodes.

"Although research so far shows the performance of soil solarization to be a little below methyl bromide, indications are that soil solarization can be incorporated into Florida growers' existing production systems," Chellemi says. "We've also shown that solarization is cost-effective and compatible with other pest management systems. We recommend

it as a viable alternative to methyl bromide for fall production systems when used within an IPM program."

New ARS/Industry Agreement To Seek Bio-Based Methyl Bromide Alternatives

ARS has a research and development agreement with Gustafson, Inc., a company in Plano, Texas, to find a multi-faceted approach to controlling nematodes and fungal pathogens in vegetable transplants. Gustafson is a leading research group and a manufacturer of seed treatment products. Nancy Kokalis-Burelle, recently hired as an ARS research ecologist at Fort Pierce, Florida, negotiated the agreement with Gustafson. She was hired by ARS to work on biologically based alternatives to methyl bromide.

Her primary aim has been to more clearly define the function of microbial interactions in biological control of foliar and soilborne fungal pathogens and nematodes. In particular, she has been studying how to manipulate microbial communities to effectively compete with plant pathogens to achieve biological control and how to successfully incorporate these strategies into integrated pest management systems.

"We're testing organic amendments, natural plant compounds, and rhizobacteria to promote plant growth," Kokalis-Burelle says. "These bacteria enhance plant

growth and protect roots from pathogens in a variety of ways. These include producing antibiotics and siderophores, which bind iron in the soil. Plant growth-promoting rhizobacteria may also induce a systemic resistance response in the host plant."

Organic amendments, such as by-products from agriculture and other industries, have also been used to control soilborne pathogens in a variety of crops, she says. "However, adding organic matter to soil to control soilborne pathogens and establish beneficial soil microflora is often impractical for large-scale field application. One alternative to field application is to add amendments to soil-less transplant mixes."

And Kokalis-Burelle will be doing that in cooperation with Gustafson, Inc., and Speedling, Inc., a company in Sun City, Florida, that just started collaboration on the project.

"Our goal is to develop a product to be added to vegetable transplant growing mixes that will provide enhanced plant growth and protection against soilborne pathogens in the field. We plan to evaluate the effect of the mixes—both with and without soil solarization—against a wide range of soilborne pests of tomato and pepper in Florida," Kokalis-Burelle reports. "The combination of amended transplant mixes with soil solarization may further enhance colonization and survival of the applied plant growth-promoting rhizobacteria and the beneficial effects of these microorganisms on host plants."

Technical Reports

Walnut Rootstock Selection for Resistance to *Phytophthora* spp.

G.T. Browne, Research Plant Pathologist, Crops Pathology and Genetics Unit, USDA, ARS, Department of Plant Pathology, UC Davis, Davis, CA 95616.

California provides about 99 percent of the U.S. walnut crop and is a world leader in walnut culture and genetic improvement efforts. Deep alluvial soils in the Sacramento and upper San Joaquin Valleys and the mild temperate climate are nearly ideal for the crop. All California walnut growers and nurserymen, however, must contend with several important soilborne pests that can debilitate and kill walnut trees of all ages. Methyl bromide has played an important role in controlling many of these pests.

Phytophthora spp. are among the most important soilborne pests of walnut. In California, more than 10 species of the fungus have been implicated as root and crown pathogens of the crop, and affected trees typically die within one or a few seasons. Periods of soil saturation with water, especially during cool to moderate temperatures, favor infection by *Phytophthora* spp. Soil saturation stimulates production and dispersal of zoospores, the principal infective propagules. Two of the most virulent species in walnut are *P. cinnamomi*, which has a limited but expanding distribution among California walnut orchards, and

P. citricola, which is somewhat less virulent but more widely distributed than *P. cinnamomi*. Some *Phytophthora* spp. can survive for extended periods (years) in soil without a living host, and evidence suggests that they are spread among orchards in surface irrigation water and by movement of infested soil and plant material.

Fumigation with methyl bromide plays an important pre-plant sanitizing role in reducing *Phytophthora* and other pest populations at commercial nursery and orchard sites. The need for genetic and cultural *Phytophthora* disease control strategies will intensify as the fumigant is banned for nursery and orchard sanitation. Although alternative chemicals to methyl bromide appear necessary at nursery sites to maintain adequate sanitation, genetic and cultural approaches offer the most effective and economical means to control many diseases caused by *Phytophthora*.

The Crops Pathology and Genetics Unit, USDA-ARS at Davis, with the University of California's Walnut Improvement Program (WIP) and commercial nurserymen cooperating, is pursuing improved genetic resistance to *Phytophthora* spp. in walnut rootstocks. Paradox hybrid seedling rootstock presently represents the available industry standard for maximum vigor, general tolerance to lesion nematodes, and resistance to most *Phytophthora* spp. Unfortunately, at least some sources of Paradox succumb to attack by *P. citricola* and *P. cinnamomi*.

Although Paradox seedlings are often described as Northern California black \times English walnut hybrids (*J. hindsii* \times *J. regia*), morphological and molecular evidence obtained by the WIP suggests that Paradox hybrids are quite diverse genetically. And, several black walnut species, such as Southern California black (*J. californica*) and Eastern black (*J. nigra*), may be serving as maternal parents of commercial Paradox rootstock seedlings.

The variation within Paradox presents an opportunity to select and develop improved hybrid rootstocks. Work is under way to determine particular hybrids, families, and clones of Paradox with superior resistance to *Phytophthora* spp. In 1997, 26 commercial Paradox hybrid seed families and four controlled hybrid crosses (provided by the WIP) were greenhouse tested for resistance to *P. citricola*. All families of Paradox sustained some root and crown rot among individual seedlings, but average severity of disease differed significantly among families. For example, nine commercial Paradox seed families were relatively susceptible to *P. citricola* (root and crown rot averages of 85–100 percent), and two were significantly more resistant (root and crown rot averages of 28–51 percent). Among the other commercial Paradox families, there was essentially a continuous range of susceptibility to root and crown rot between the relatively susceptible and resistant families. Among the four controlled-cross seed families, Arizona Paradox hybrid (*J. major* \times *J. regia*) was significantly more

resistant (root and crown rot averages of 43 percent) than a Southern California hybrid family (*J. californica* × *J. regia*, root and crown rot averages of 87–96 percent) and two Northern California black hybrid families (*J. hindsii* × *J. regia*, root and crown rot averages of 79–99 percent).

Chinese wingnut (*Pterocarya stenoptera*) has the highest known genetic resistance to *Phytophthora* spp. among potential walnut rootstocks. Previous ARS research at Davis revealed that at least some sources of Chinese wingnut are very resistant to all *Phytophthora* spp. that commonly affect walnuts, including *P. citricola* and *P. cinnamomi*. In 1974, Lownsbery et. al reported that Chinese wingnut was more tolerant to lesion nematode than Northern California black, English, or Paradox hybrid rootstocks.

The main obstacle in using wingnut as a rootstock is limited graft compatibility with English walnut cultivars. In an 11-year ARS experiment completed in 1997, one seed source of wingnut was graft compatible with four of eleven English walnut cultivars, but wingnut compatibility with recently released walnut cultivars remains unknown. More work has been initiated with commercial nurseries to evaluate graft compatibility of six diverse wingnut seed sources with six prevalent English cultivars. We will also evaluate wingnut-compatible English cultivars as interstock “bridges” between wingnut and wingnut-incompatible English cultivars.

To determine if resistance to *Phytophthora* is uniformly present among the diverse wingnut sources being tested for graft compatibility, greenhouse screens with *P. citricola* and *P. cinnamomi* were completed. In these tests, all wingnut sources were highly resistant to *P. citricola* (root and crown rot averages of 0–1 percent) and moderately resistant to *P. cinnamomi* (root and crown rot averages of 8–36 percent), whereas standards of Paradox, Northern California black, and English seedling rootstock were relatively susceptible (root and crown rot averages of 65–100 percent with *P. citricola* and 69–100 percent with *P. cinnamomi*). ARS-Davis is cooperating with UC scientists M.V. McKenry and B.B. Westerdahl in evaluating lesion nematode tolerance among the six wingnut sources and standards of Paradox, English, and Northern California black rootstock.

Results of 1997 *Phytophthora* screens show important variation in genetic resistance to *P. citricola* among a limited number of Paradox seed families and indicate good resistance to *P. cinnamomi* and *P. citricola* among Chinese wingnuts from diverse sources. Repeat experiments are needed to confirm these findings.

Rootstocks with improved genetic resistance to *Phytophthora* spp. may provide a key link in methyl bromide alternative strategies for walnut production.

Moving Toward Integrated Management of Root Diseases in Northern Forest Nurseries

Jennifer Juzwik, research plant pathologist, USDA Forest Service, and Raymond Allmaras, research soil scientist, USDA-ARS, St. Paul, MN 55108.

Soil-borne diseases may result in significant mortality of nursery tree seedlings and negatively affect growth and quality of live seedlings remaining for lifting (i.e., harvesting) and shipping. Seedlings that have been morphologically (e.g., shoot height or root volume) or physiologically impaired in the nursery and that are shipped for out-planting may die or grow poorly during the first several years on the planting site, be it a reforestation area, a farm field conversion, or a conservation planting.

Based on a 1992 national survey of U.S. forest nursery managers, over 80 percent reportedly relied on methyl bromide for pre-plant soil fumigation in efforts to grow quality seedlings. Other soil fumigants (e.g., metam sodium and dazomet) have been used successfully by a small minority of nurseries; while even fewer nurseries produce stock without any soil fumigation.

Nursery cultural practices, especially those involving soil management, are important in controlling root diseases. Practices that influence the occurrence and severity of these diseases include soil tillage, soil water management, mulching, sowing of infested

seed, fertilization, and soil fumigation. In the past fumigation has been the preferred pest management option and the primary means of controlling root rot in bare-root nurseries. Unfortunately the heavy reliance on a single “tool” that focuses on the disease organism(s) may lead nursery managers away from considering the soil conditions that actually predispose seedlings to infection by pathogens and are a result of cultural practices.

From 1994 to 1996 investigations were conducted in five northern nurseries with varying cultural regimes to: 1) document physical and biological soil conditions resulting from each nursery's practices and consider their relationship to root rot development, and 2) interpret operational fumigation practices in view of these conditions. The results of the studies suggest a number of non-chemical control actions that could be readily implemented in an integrated manner with or without soil fumigants to control root rot.

Resistance of nursery soils to penetration was measured at 15-mm increments from the soil surface to a 42 cm depth in fields with 2-year-old pine seedlings at three nurseries. The soils in these fields ranged from loamy sands to sand soils. Significant increases in the force required to insert the cone penetrometer at a controlled speed is indicative of compacted soil layers or hardpans. The resulting graph of the cone indices through the soil depth revealed a profile with two peaks of increased resistance in the Minnesota and the Wisconsin study nurseries, while

no such peaks were found for the Michigan nursery studied. The more shallow hardpan (10- to 15-cm depth) was attributed to the use of rotary tillers in fields just prior to sowing of the pine crop but after sub-soiling had been performed. The second pan (30- to 36-cm depth) was attributed to moldboard plow use for incorporation of cover crops at the nurseries. This pan was partially mitigated by sub-soiling that occurred after plow use. The absence of pans in the Michigan nursery was attributed to the use of a disk for all soil-disturbing operations.

The rate of water movement through portions of the soil profile was also determined. Undisturbed soil cores (5-cm long \times 5-cm dia) were removed and rate of water flow through cores was determined in the laboratory using saturated hydraulic conductivity methods. Reduced rates were associated with the tiller-compacted zone (e.g., 14.4 cm/hr, Wisconsin nursery) compared to the rates for cores from the same depth zone in non-compacted field areas (e.g., avg. 18.4 cm/hr, same nursery). Root disease occurrence in white pine seedlings, based on visual rating of seeding roots, was also higher in portions of fields with tiller pans.

The number of *Fusarium* species propagules per gram of dry soil in 6-cm depth increments from the soil surface to 42-cm depth was also determined for the same three nurseries. The resulting graphs of the propagule numbers versus increasing soil depth revealed similar *Fusarium* population profiles for the Minnesota and the

Wisconsin nurseries, but a different profile for the Michigan nursery. Population peaks observed in the 0- to 6-inch zone in Minnesota and Wisconsin fields were attributable to recolonization and increase by the fungus that occurred after soil fumigation (metam sodium in the first nursery, methyl bromide in the second). The deeper peak (18- to 24-cm zone) was attributed to *Fusarium* that increased on carbon sources from incorporated cover crop material and “survived” soil fumigation. Moldboard plows place 90 percent of surface residue just above the maximum working depth of the implement (i.e., 18 to 24 cm in these two nurseries). Previous studies in two other Wisconsin nurseries have found methyl bromide fumigation to be only partially effective in the 15- to 25-cm depth zone. In the Michigan nursery where no fumigation occurred, the *Fusarium* populations were highest at the soil surface and decreased to negligible levels below 17 cm. This profile corresponds to the surface residue burial pattern characteristic of a disk.

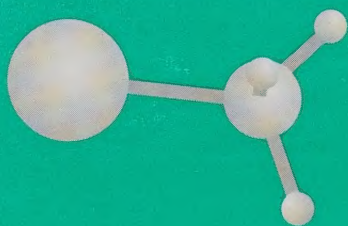
In two additional nurseries, the effect of fumigation depth on vertical distribution of *Fusarium* in soil was determined. In a 1994 Wisconsin nursery trial, 560 kg/ha of dazomet was applied to the soil surface with a Gandy spreader and immediately incorporated into the sandy loam soil (moisture content at 60 percent field capacity) using either a rotary tiller with 22-cm-long, bent tines or a spading machine with six 13-cm-wide by 18-cm-long blades. The operational incorporation depth of the

latter was known to be twice that of the rotary tiller used. The spading machine incorporation resulted in excellent and sustained reduction in *Fusarium* propagules at a 6- to 30-cm depth through the second growing season. In contrast, the rotary tiller incorporation of dazomet resulted in similar and sustained reduction in *Fusarium* only between a depth of 6- and 18-cm. Because cover crop material had been incorporated by mold-board plow in this field, a *Fusarium* peak between 18 and 24 cm was only partially affected by the more shallow incorporation with a rotary tiller compared to nearly total control when deeper fumigant incorporation was achieved.

In comparison, a second similar trial was conducted in another Michigan nursery where a disk was used for cover crop incorporation and surface residue was placed in the 0- to 18-cm zone. Pre-fumigation *Fusarium* populations were significant only between 0 and 15 cm, and negligible below. All three dazomet incorporation implements tested at this nursery (rotary tiller, spading machine, and disk) were equally effective in significantly reducing *Fusarium* in the 0- to 15-cm zone.

In summary, nurseries could use tillage to control depth placement of cover crop residue and subsequent buildup of fungal propagules, adjust tillage practices to prevent hardpan creation within the seedling rooting zone, and maintain optimal soil moisture conditions for seedling growth in their integrated management of root disease in pine crops. Consid-

eration of tillage practices effects on residue placement can also be the basis for more effective and wise use of soil fumigation.



Upcoming Meetings

Pittsburgh, Pennsylvania—September 16–17, 1998

The 6th International Activated Carbon Conference is being held at the Pittsburgh Plaza Hotel in Pittsburgh, Pennsylvania, September 16–17, 1998.

Oral and poster presentations are welcome, and there will be short courses offered before and after the conference. For additional information or to submit abstracts, contact Henry Nowicki at PACS, Inc., 409 Meade Drive, Moon, PA 15108; phone (800) 367–2587 or (724) 457–6576; fax (724) 457–1214; e-mail HNpacs@aol.com. Or, visit the web site: <http://members.aol.com/HNpacs/pacs.htm>.

Orlando, Florida—December 7–9, 1998

Note the change in date for the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reduction. Usually this meeting is held in November, but this year it is scheduled for December 7–9 at the Omni Rosen Hotel in Orlando, Florida, phone (407) 354–9840 or (800) 800–9840, fax (407) 351–2659. More information will appear in the July issue of *Methyl Bromide Alternatives*. Immediate questions should be addressed to the Methyl Bromide Alternatives Outreach, 144 W. Peace River Drive, Fresno, CA, phone (209) 447–2127, fax (209) 436–0692.

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